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OFFICE OF NAVAL RESEARCH
FINAL TECHNICAL REPORT

for

Contract N00014-86-K-0545

R&T Code 4134011

"Studies of Chemistry and Diffusion on
Silicon and Gallium Arsenide Surfaces
Using Laser-Induced Thermal Desorption"

Dr. Steven M. George
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Stanford University
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Outline - Final Technical Report

I. Overview.....	3
A. Principal Investigator	
B. Cognizant ONR Scientific Officer	
C. Current Telephone Numbers	
D. Brief Description of Completed Project	
II. Significant Results from ONR Contract Support.....	4
A. Hydrogen Desorption Kinetics from Silicon Surfaces	
B. Adsorption Kinetics of O ₂ on Si(111)7x7	
C. Laser Induced Desorption of Silicon-Containing Surface Reaction Intermediates	
D. Decomposition of H ₂ O on Si(111)7x7	
E. Decomposition of NH ₃ on Si(111)7x7	
III. Graduate Students Working on Project.....	7
IV. Publications Resulting from ONR Contract.....	8
V. Manuscripts in Press or Preparation Resulting from ONR Contract.....	10
VI. Invited Talks on Supported Work.....	13
VII. Contributed Talks on Supported Work.....	17
VIII. Contributed Posters on Supported Work.....	21

I. Overview

A. Principal Investigator

Dr. Steven M. George
Dept. of Chemistry
Stanford University
Stanford, Calif. 94305

B. Cognizant ONR Scientific Officer

Dr. David L. Nelson / Dr. Mark Ross

C. Current Telephone Numbers

(415) 725-0270 (Office)
(415) 723-5918 (Lab)
(415) 723-1236 (Secretary)

D. Brief Description of Completed Project

Surface chemistry and surface diffusion play pivotal roles in semiconductor processing and must be understood as electronic device dimensions approach the submicron level. In this project, basic time-dependent processes on silicon surfaces were examined using laser induced thermal desorption (LITD) and Fourier transform infrared (FTIR) spectroscopy. These techniques provided direct, quantitative measurements of surface coverage in real-time. Using LITD and FTIR techniques, emphasis was on a microscopic understanding of semiconductor surface reaction kinetics. *JL*

The major areas addressed were the kinetics of fundamental semiconductor processing steps such as: surface oxidation and nitridation; epitaxial growth on surfaces; and surface etching. The Si(111)7x7 single crystal surface, as well as porous silicon surface, were used as the model semiconductor surfaces. These studies were conducted in UHV using Auger spectroscopy and LEED spectroscopy for surface analysis and characterization. The kinetic parameters that were determined by these LITD and FTIR studies are crucial for the understanding and modeling of semiconductor processing chemistry.

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II. Significant Results from ONR Contract Support

This ONR sponsored research addressed the kinetics of fundamental surface reactions relevant to semiconductor processing chemistry. This section will highlight the research that has been published recently in refereed journals. Our more recent research on various chlorosilanes and chlorogermanes that are important in silicon and germanium epitaxy was initiated at the end of this ONR contract support and is still under investigation. This research will be discussed in future end-of-the-year reports for ONR N00014-90-J-1281.

A. Hydrogen Desorption Kinetics from Silicon Surfaces

Hydrogen plays a key role in silicon surface chemistry. Our initial LITD and FTIR studies explored the desorption kinetics of H_2 from Si(111)7x7 and porous silicon surfaces [1-3]. These investigations established the different thermal stabilities of monohydride and dihydride species. Moreover, these studies obtained kinetic parameters for monohydride and dihydride desorption. These kinetic parameters are useful for understanding the basic interaction of hydrogen with silicon surfaces and for modeling various CVD silicon processing steps.

B. Adsorption Kinetics of O_2 on Si(111)7x7

Oxygen forms an insulating oxide layer upon reaction with silicon surfaces. The details of oxygen adsorption and oxide growth in the submonolayer and monolayer regime have been debated actively. Our second major study addressed the initial growth of the silicon oxide layer on Si(111)7x7 [6,8]. We measured a

temperature-dependent sticking coefficient that decreased with temperature indicating a precursor adsorption mechanism. In addition, a temperature-dependent apparent saturation coverage was revealed that increased dramatically with surface temperature. These results should be useful for a complete understanding of silicon surface oxidation and models of silicon oxide growth in the thin film limit.

C. Laser-Induced Desorption of Silicon-Containing Surface Reaction Intermediates

During the examination of the LITD yield from Si(111)7x7 surfaces exposed to H₂O and NH₃, we discovered the presence of silicon-containing LITD species in the form of SiOH and SiNH₂ [4]. Additional examination of a hydrogen-saturated Si(111)7x7 surface revealed SiH₂ LITD products. Likewise, the Si(111)7x7 exposed to CH₃OH produced SiOCH₃ LITD species. These silicon-containing species were intriguing and suggested that laser desorption was able to desorb these surface reaction intermediates directly from the silicon surface. Subsequent FTIR investigations have confirmed that the silicon-containing LITD products correspond to silicon surface reaction intermediates. The ability of LITD to remove these reaction intermediates is extremely useful for kinetic studies of decomposition on silicon surfaces as discussed below.

D. Decomposition of H₂O on Si(111)7x7

Making use of the ability of LITD to desorb silicon-containing surface reaction intermediates, the decomposition of

H₂O was examined on Si(111)7x7 [5]. This study established the thermal stability of the SiOH species and monitored its decomposition between 400-600 K prior to H₂ desorption at 800 K and SiO desorption at 950 K. The decomposition kinetics for SiOH were self-poisoning at high coverages suggesting that the availability of free dangling-bond surface sites controls the reaction. Experiments with preadsorbed hydrogen also revealed surface passivation as hydrogen ties up free surface dangling bonds. These results are probably transferable to many decomposition reactions on silicon surfaces and should be especially useful in understanding the formation of insulating silicon oxide layers with H₂O oxidation.

E. Decomposition of NH₃ on Si(111)7x7

NH₃ is commonly employed to grow insulating silicon nitride layers. Like H₂O decomposition, NH₃ decomposes to yield hydrogen on the silicon surface. The availability of free surface sites may also be expected to control the surface reaction rates. By monitoring the SiNH₂ LITD species, the thermal stability and decomposition rates of the SiNH₂ surface reaction intermediate were studied on Si(111)7x7 [7]. The expected parallels between SiNH₂ and SiOH were established. In addition, a SiNH LITD species was observed that displayed different decomposition kinetics than SiNH₂ and suggested a partially step-wise decomposition of SiNH₂. Moreover, the effect of preadsorbed hydrogen was observed to passivate the Si(111)7x7 surface and reduce the NH₃ decomposition yield. These results should be useful for an understanding of silicon nitride film growth.

III. Graduate Students Working on Project

Five graduate students worked on various aspects of this ONR sponsored research:

1. Chi Mak. Entered Stanford 1984. Graduated 1988. NSF Fellow. Worked on LITD studies of H₂ desorption, O₂ adsorption and H₂O decomposition on Si(111)7x7. Postdoc work at U.C. Berkeley. Starts faculty position at USC, Fall, 1990.
2. Birgit Koehler. Entered Stanford 1985. Graduates Spring 1990. NSF Graduate Fellow. Worked on LITD studies of H₂ desorption, H₂O and NH₃ decomposition, SiCl₄ adsorption and desorption on Si(111)7x7. Starts postdoc at SRI, summer 1990.
3. Kim Gupta. Entered Stanford 1985. Graduates Fall 1990. Worked on FTIR studies of H₂ desorption and O₂ oxidation of porous silicon. Worked on LITD studies of O₂ adsorption, SiCl₄ adsorption and desorption on Si(111)7x7. Accepted job with Intel-Santa Clara, Fall 1990.
4. Peter Coon. Entered Stanford 1987. Has worked on all LITD studies of adsorption, decomposition and desorption from Si(111)7x7. Third year student.
5. Anne Dillon. Entered Stanford 1988. Has worked on all new FTIR research on H₂O decomposition and NH₃ decomposition on porous silicon. Second year student.

IV. Publications Resulting from ONR Contract

1. Authors: P.Gupta, V.L. Colvin and S.M. George
Title: "Hydrogen Desorption Kinetics from Monohydride and Dihydride Species on Silicon Surfaces"
Journal: Physical Review B 37, 8234 (1988).
2. Authors: B.G. Koehler, C.H. Mak, D.A. Arthur and S.M. George
Title: "Desorption Kinetics of Hydrogen from Si(111)7x7 Studied Using Laser Induced Thermal Desorption"
Journal: Journal of Chemical Physics 89, 1079, (1988).
3. Authors: P. Gupta, V.L. Colvin, J.L. Brand and S.M. George
Title: "Hydrogen Desorption Kinetics from Silicon Surfaces Using Transmission FTIR" in Decomposition and Growth: Limits for Microelectronics
Publisher: American Vacuum Society, edited by G.W. Rubloff
4. Authors: C.H. Mak, B.G. Koehler and S.M. George
Title: "Laser-Induced Thermal Desorption of Silicon-Containing Surface Reaction Intermediates from Si(111)7x7"
Journal: Surface Science 208, L42 (1989)
5. Authors: B.G. Koehler, C.H. Mak and S.M. George
Title: "Decomposition of H₂O on Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"
Journal: Surface Science 221, 565 (1989)
6. Authors: P. Gupta, C.H. Mak, P.A. Coon and S.M. George
Title: "Oxidation Kinetics of Si(111)7x7 in the Submonolayer Regime"
Journal: Physical Review B40, 7739 (1989)

7. Authors: B.G. Koehler, P.A. Coon and S.M. George
Title: "Decomposition of NH_3 on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"
Journal: Journal of Vacuum Science Technology B7, 1303 (1989)
8. Authors: S.M. George, P. Gupta, C.H. Mak and P.A. Coon
Title: "Oxidation Kinetics of Silicon Surfaces: Reactive Sticking Coefficient, Apparent Saturation Coverage and Effect of Surface Hydrogen", in Chemical Perspectives of Microelectronic Materials"
Journal: Material Research Society Symposium Proceedings 131, 169 (1989)
9. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
Title: "Adsorption of Silicon Tetrachloride on Si(111)7x7", in Chemical Perspectives of Microelectronic Materials"
Publisher: Material Research Society Symposium Proceedings 131, 197 (1989)

V. Manuscripts in Press or Preparation Resulting from ONR Contract

1. Authors: P. Gupta, C.H. Mak, P.A. Coon and S.M. George
Title: "Kinetics of H₂O Adsorption on Si(111)7x7"
Journal: Surface Science Letters (in preparation for submission)
2. Authors: P. Gupta, A.S. Bracker, V.L. Colvin and S.M. George
Title: "Oxidation Kinetics of Porous Silicon Studied Using Transmission FTIR"
Journal: Journal of Electrochemical Society (in preparation for submission)
3. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
Title: "Adsorption and Desorption Kinetics for SiCl₄ on Si(111)7x7"
Journal: Journal of Chemical Physics (in press)
4. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
Title: "Adsorption and Desorption Kinetics for Cl₂ on Si(111)7x7"
Journal: (in preparation for submission)
5. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
Title: "Adsorption and Desorption Kinetics for SiCl₂H₂ on Si(111)7x7"
Journal: (in preparation for submission)
6. Authors: P.A. Coon, P. Gupta, B.G. Koehler and S.M. George
Title: "Surface Hydride Species on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"
Journal: (in preparation for submission)

7. Authors: B.G. Koehler and S.M. George
Title: "Laser Induced Thermal Desorption from Si(111)7x7: I. Numerical Calculations"
Journal: (in preparation for submission)
8. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
Title: "Laser Induced Thermal Desorption from Si(111)7x7: II. Hydrogen Isothermal Desorption Kinetics"
Journal: (in preparation for submission)
9. Authors: P. Gupta, A.C. Dillon, A.S. Bracker and S.M. George
Title: "Decomposition of H₂O on Silicon Surfaces Studied Using Transmission FTIR"
Journal: (in preparation for submission)
10. Authors: A.C. Dillon, P. Gupta, A.S. Bracker and S.M. George
Title: "Decomposition of NH₃ on Silicon Surfaces Studied Using Transmission FTIR"
Journal: (in preparation for submission)
11. Authors: S.M. George, P. Gupta, B.G. Koehler, C.H. Mak and P.A. Coon
Title: "Laser Induced Thermal Desorption Studies of Reaction Kinetics on Si(111)7x7"
Journal: Proceedings of MicroProcess '89 Japan Journal of Applied Physics (1990)
12. Authors: S.M. George, P. Gupta, B.G. Koehler, P.A. Coon, A.C. Dillon and C.H. Mak
Title: "Silicon Surface Kinetics Studied Using Laser Induced Thermal Desorption"
Journal: Laser Photoionization and Desorption Surface Analysis Techniques, SPIE Conference Proceedings, (SPIE, Bellingham, WA., 1990)

13. Authors: S.M. George, P. Gupta, B.G. Koehler, P.A.
Coon, A.C. Dillon and C.H. Mak

Title: "Optical Probes of Silicon Surface Chemistry"

Journal: Proceedings of Sixth International Symposium
on Silicon Materials Science and Technology,
Journal of Electrochemical Society

VI. Invited Talks on Supported Work

1. "Diffusion and Desorption of Hydrogen on Surfaces"

Xerox Palo Alto Research Center
Electronics Materials Laboratory
Palo Alto, Calif.
June 19, 1987

2. "Diffusion and Desorption of Hydrogen on Surfaces"

Signetics Phillips Research Center
Sunnyvale, Calif.
June 23, 1987

3. "Oxidation Kinetics of Silicon Surfaces
in the Submonolayer Regime"

Intel Corporation
Santa Clara, Calif.
April 26, 1988

4. "Reaction Kinetics on Si(111) 7x7 Studied Using Laser
Induced Thermal Desorption"

Xerox Palo Alto Research Center
Electronics Materials Laboratory
Palo Alto, Calif.
Sept. 9, 1988

5. "Reaction Kinetics on Silicon Surfaces"

Dept. of Chemistry
Massachusetts Inst. of Technology
Cambridge, Mass.
Sept. 13, 1988

6. "Reaction Kinetics on Silicon Surfaces"

Hewlett-Packard Research Center
Palo Alto, Calif.
Oct. 18, 1988

7. "Oxidation Kinetics of Silicon Surfaces"

Symposium on Chemical Prospectives in Microelectronics
Materials Research Society Fall Meeting
Boston, Mass.
Dec. 1, 1988

8. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
California Institute of Technology
Pasadena, Calif.
January 24, 1989

9. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
University of California at San Diego
La Jolla, Calif.
January 31, 1989

10. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
University of Texas at Austin
Austin, Texas
Feb. 23, 1989

11. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
Texas A & M University
College Station, Texas
Feb. 24, 1989

12. "Oxidation Kinetics of Silicon Surfaces"

Topical Meeting on Microphysics of Surfaces, Beams and Adsorbates
Salt Lake City, Utah
February 27, 1989

13. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Dept. of Chemistry
Princeton University
Princeton, NJ
March 15, 1989

14. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Dept. of Chemistry
University of Pennsylvania
Philadelphia, Penn.
March 16, 1989

15. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

ATT Bell Laboratories
Murray Hill, NJ
March 17, 1989

16. "Studies of Reaction Kinetics on Silicon Surfaces Using FTIR"

Stanford Materials Research Forum
Dept. of Materials Science and Engineering
Stanford University
Stanford, CA
May 5, 1989

17. "Laser Induced Thermal Desorption Studies of Reaction Kinetics on Si(111) 7x7"

International MicroProcess Conference 1989
Japan Society of Applied Physics
Kobe, Japan
July 4, 1989

18. "Reaction Kinetics on Si(111): 7x7 Surfaces Studied Using Laser-Induced Thermal Desorption"

Condensed Matter Seminar
Univ. of California at Berkeley
Berkeley, Calif.
September 20, 1989

19. "Surface Kinetics Studies Using Laser-Induced Thermal Desorption"

Symposium on Laser Photoionization and Desorption
Surface Analysis Techniques
SPIE National Meeting
Los Angeles, Calif.
January 18, 1990

20. "Reaction Kinetics on Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"

Gordon Research Conference on The Chemistry of
Electronic Materials
Ventura, Calif.
March 1, 1990

VII. Contributed Talks on Supported Work

1. "Transmission FTIR Studies of Porous Silicon"
P. Gupta, V.L. Colvin and S.M. George
Am. Chem. Soc. Natl. Meeting
Denver, Colorado
April 10, 1987

2. "Hydrogen Desorption Kinetics from Mono and Dihydride Species on Silicon Surfaces Using Transmission FTIR"
P. Gupta, V.L. Colvin, J.L. Brand and S.M. George
Am. Vac. Soc. Natl. Meeting
Anaheim, Calif.
Nov. 3, 1987

3. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"
P. Gupta, C.H. Mak, P.A. Coon and S.M. George
ACS Symposium on "General Papers in Catalysis"
Natl. Meeting of the American Chemical Society
Los Angeles, Calif.
Sept. 28, 1988

4. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"
P. Gupta, C.H. Mak, P.A. Coon and S.M. George
Pacific Conference on Chemistry and Spectroscopy
San Francisco, Calif.
Oct. 26, 1988

5. "Decomposition of NH_3 on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"
B.G. Koehler, P.A. Coon and S.M. George
Topical Meeting on Microphysics of Surfaces, Beams and Adsorbates
Salt Lake City, Utah
March 1, 1989

6. "Decomposition of NH_3 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"
B.G. Koehler, P.A. Coon, and S.M. George
Northern Calif. Am. Vacuum Society Meeting
Stanford Linear Accelerator Center
Stanford, Calif.
June 1, 1989
7. "Decomposition of NH_3 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"
B.G. Koehler, P.A. Coon, and S.M. George
Sixty-third Colloid and Surface Science Symposium
Sponsored by the American Chemical Society
University of Washington
Seattle, Wash.
June 21, 1989
8. "Adsorption and Desorption of SiCl_4 on Si(111) 7x7"
P. Gupta, P.A. Coon, B.G. Koehler, and S.M. George
Sixty-third Colloid and Surface Science Symposium
Sponsored by the American Chemical Society
University of Washington
Seattle, Washington
June 21, 1989
9. "Decomposition of NH_3 and H_2O on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"
B.G. Koehler, P.A. Coon, C.H. Mak and S.M. George
Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989
10. "Laser Induced Thermal Desorption for Studies of Surface Reaction Kinetics"
S.M. George, B.G. Koehler, C.H. Mak, P. Gupta and P.A. Coon
5th Interdisciplinary Laser Science Conference
Stanford University
Stanford, Calif.
August 30, 1989

11. "Laser Heating and Laser-Induced Desorption:
Experimental and Theoretical Results for Silicon
Surfaces"

B.G. Koehler, P. Gupta, P.A. Coon and S.M. George

5th Interdisciplinary Laser Science Conference
Stanford University
Stanford, Calif.
August 30, 1989

12. "Decomposition of NH_3 on Si(111) 7x7 Studied Using
Laser-Induced Thermal Desorption"

B.G. Koehler, P.A. Coon, P. Gupta and S.M. George

Am. Vac. Soc. Natl. Meeting
Boston, Mass.
October 24, 1989

13. "Adsorption and Desorption Kinetics for SiCl_4 on
Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

Am. Vac. Soc. Natl. Meeting
Boston, Mass.
October 26, 1989

14. "Oxidation Kinetics of Si(111) 7x7 in the Submonolayer
Regime"

S.M. George, P. Gupta, C.H. Mak and P.A. Coon

Am. Inst. Chem. Eng. 1989 Annual Meeting
Symposium on Kinetics and Mechanisms in
Electronics Materials Processing
San Francisco, Calif.
Nov. 8, 1989

15. "Adsorption and Desorption Kinetics for SiCl_4 on
Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

Am. Inst. Chem. Eng. 1989 Annual Meeting
Symposium on Kinetics and Mechanisms in
Electronics Materials Processing
San Francisco, Calif.
Nov. 9, 1989

16. "Kinetics of H₂O Adsorption and Decomposition on Si(111)
7x7"

B.G. Koehler, P.A. Coon, P. Gupta and S.M. George

Am. Inst. Chem. Eng. 1989 Annual Meeting
Symposium on Kinetics and Mechanisms in
Electronics Materials Processing
San Francisco, Calif.
Nov. 9, 1989

VIII. Contributed Posters on Supported Work

1. "Porous Silicon: Chemical and Physical Characterization"
P. Gupta and S.M. George
Gordon Research Conf. on the Chemistry of
Electronic Materials
St. Paul's Academy, Concord, New Hampshire
August 20, 1986

2. "Transmission FTIR Spectroscopy on Porous Silicon"
P. Gupta and S.M. George
Western Spectroscopy Association Annual Conf.
Asilomar, Calif.
Jan. 29, 1987

3. "Studies of Adsorbates on Porous Silicon Using
Transmission FTIR Spectroscopy"
P. Gupta, J.L. Brand and S.M. George
Northern Calif. Am. Vac. Soc. Meeting
IBM Almaden Research Center
San Jose, Calif.
Feb. 25, 1987

4. "Desorption Kinetics of Hydrogen from Silicon
Surfaces Using Transmission FTIR"
P. Gupta, V.L. Colvin and S.M. George
Gordon Research Conf. on the Dynamics of Gas-
Surface Interactions
Proctor Academy, Andover, New Hampshire
Aug. 13, 1987

5. "Desorption Kinetics of Hydrogen From Si(111)7x7
Measured Using Laser-Induced Thermal Desorption"
B.G. Koehler, C.H. Mak, D.A. Arthur and S.M. George
Gordon Research Conf. on the Chemistry of Thin Films
Colby-Sawyer College
New London, New Hampshire
Aug. 12, 1987

6. "Hydrogen Desorption Kinetics and Oxygen Reaction Kinetics on Silicon Surfaces"
P. Gupta, V.L. Colvin and S.M. George
Northern Calif. Am. Vac. Soc. Meeting
Sandia Natl. Lab.
Livermore, Calif.
Dec. 9, 1987
7. "Hydrogen Desorption Kinetics from Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"
B.G. Koehler, C.H. Mak, D.A. Arthur, P.A. Coon and S.M. George
Northern Calif. Am. Vac. Soc. Meeting
Sandia Natl. Lab.
Livermore, Calif.
Dec. 9, 1987
8. "Initial Oxygen Reactions Kinetics on Silicon Surfaces"
P. Gupta, V. Colvin and S.M. George
Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988
9. "Desorption Kinetics of Hydrogen and Deuterium From Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"
B.G. Koehler, C.H. Mak, D.A. Arthur, P.A. Coon, and S.M. George
Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988
10. "The Effects of Decomposition Products on the Reaction of Water with Si(111) 7x7"
B.G. Koehler, C.H. Mak, S.M. George
Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988

11. "Initial Oxygen Reaction Kinetics on Silicon Surfaces"
P. Gupta, V.L. Colvin and S.M. George
Gordon Research Conf. on Chemistry of
Electronic Materials
Ventura, Calif.
March 7-11, 1988

12. "Desorption Kinetics of Hydrogen and Deuterium
from Si(111) 7x7 Studied Using Laser-Induced
Thermal Desorption"
B.G. Koehler, C.H. Mak, D.A. Arthur, P.A. Coon
and S.M. George
Gordon Research Conf. on Chemistry of
Electronic Materials
Ventura, Calif.
March 7-11, 1988

13. "The Effects of Decomposition Products of the
Reaction of Water with Si(111) 7x7"
B.G. Koehler, C.H. Mak, S.M. George
Gordon Research Conf. on Chemistry of
Electronic Materials
Ventura, Calif.
March 7-11, 1988

14. "Laser-Induced Thermal Desorption of Silicon-
Containing Intermediates from Si(111) 7x7"
C.H. Mak, B.G. Koehler and S.M. George
Gordon Research Conf. on Chemistry of Electronic
Materials
Ventura, Calif.
March 7-11, 1988

15. "Oxidation Kinetics of Silicon Surfaces in the
Submonolayer Regime"
P. Gupta, C.H. Mak, P.A. Coon, and S.M. George
Northern Calif. Am. Vacuum Society Meeting
IBM Almaden Research Center
San Jose, Calif.
June 3, 1988

16. "The Decomposition of H₂O on Si(111)7x7: Effect of Preadsorbed Hydrogen and Observation of Surface Intermediates"
- B.G. Koehler, C.H. Mak, and S.M. George
- Northern Calif. Am. Vacuum Society Meeting
IBM Almaden Research Center
San Jose, Calif.
June 3, 1988
17. "Adsorption/Desorption Kinetics of SiCl₄ on Si(111) 7X7"
- P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
- Symposium on Chemical Prospectives in Microelectronics
Materials Research Society Fall Meeting
Boston, Mass.
Dec. 1, 1988
18. "Decomposition of H₂O on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"
- B.G. Koehler, P.A. Coon, C.H. Mak, and S.M. George
- Northern Calif. Am. Vacuum Society Meeting
Stanford Linear Accelerator Center
Stanford, Calif.
June 1, 1989
19. "Adsorption and Desorption Kinetics for SiCl₄ on Si(111) 7x7"
- P. Gupta, P.A. Coon, B.G. Koehler and S.M. George
- Northern Calif. Am. Vacuum Society Meeting
Stanford Linear Accelerator Center
Stanford, Calif.
June 1, 1989
20. "The Decomposition of NH₃ on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption."
- B.G. Koehler, P.A. Coon, and S.M. George
- Gordon Research Conference on Inorganic Thin Films
and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

21. "Kinetics of H₂O Adsorption and Decomposition on Si(111) 7x7.

B.G. Koehler, P. Gupta, C.H. Mak, P.A. Coon, and S.M. George

Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

22. "Adsorption and Desorption of SiCl₄ on Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler, and S.M. George

Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

23. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"

P. Gupta, C.H. Mak, P.A. Coon and S.M. George

Am. Vac. Soc. Natl. Meeting
Boston, Mass.
October 26, 1989

24. "FTIR Studies of H₂O and NH₃ Decomposition on Silicon Surfaces"

A.C. Dillon, P. Gupta, A.S. Bracker, M.B. Robinson and S.M. George

Western Spectroscopy Association
37th Annual Conference
Asilomar Conference Center
Pacific Grove, Calif.
January 24-26, 1990

25. "Silicon Hydride Species on Si(111)7x7 Studies using Laser-Induced Thermal Desorption"

P.A. Coon, P. Gupta, B.G. Koehler, and S.M. George

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990

26. "FTIR Studies of NH_3 Decomposition on Silicon Surfaces"
A.C. Dillon, P. Gupta, A.S. Bracker and S.M. George
Gordon Research Conference on The Chemistry of
Electronic Materials
Ventura, Calif.
March 1, 1990
27. "Reactions of Chlorosilanes on Si(111)7x7 Studied Using
Laser-Induced Thermal Desorption"
P.Gupta, P.A. Coon, B.G. Koehler, and S.M. George
Gordon Research Conference on The Chemistry of
Electronic Materials
Ventura, Calif.
March 1, 1990
28. "FTIR Studies of H_2O Decomposition on Silicon Surfaces"
P. Gupta, A.C. Dillon, A.S. Bracker, M.B. Robinson and
S.M. George
Gordon Research Conference on The Chemistry of
Electronic Materials
Ventura, Calif.
March 1, 1990
29. "Experimental and Theoretical Studies of H_2 Laser-
Induced Thermal Desorption from Si(111)7x7"
B.G. Koehler, P.A. Coon, P. Gupta and S.M. George
Gordon Research Conference on The Chemistry of
Electronic Materials
Ventura, Calif.
March 1, 1990